

Operational AIRS-MODIS Co-location System

**AIRS Spatial Response Function &
MODIS IR channel Spectral Response Function**

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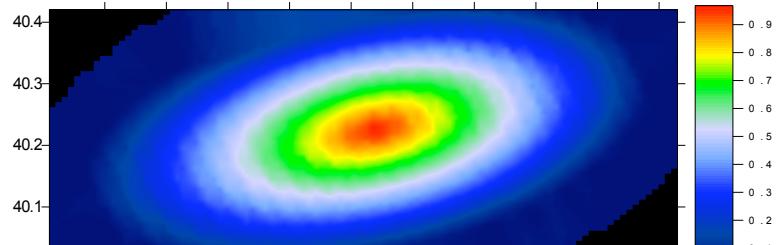
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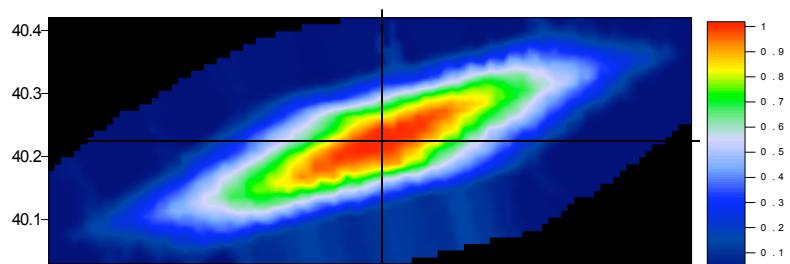
AIRS-MODIS Collocation Processing in ORA

- Operational Collocation Algorithms: Co-register observations from AIRS and MODIS
- AIRS spatial response function simulation
- Algorithm validation analysis and results
- MODIS IR channel spectral response function .
- Summary

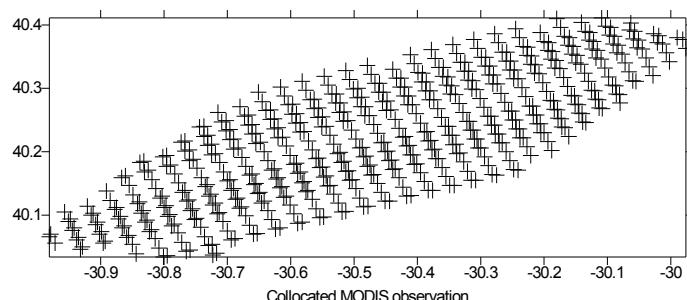
Apply AIRS EFOV Spatial Response Function for Collocations



Simplified AIRS EFOV SRF .Fp=1



Simulated AIRS EFOV SRF Fp=1



Collocated MODIS observation

The AIRS radiance is contributed by all the points within the EFOV of the sensor.

In one AIRS EFOV, hundreds of MODIS observations are collocated.

A more realistic AIRS EFOV Spatial Response Function is used to:

1: Select collocated MODIS observations

2: Calculate the weights for each MODIS FOV

AIRS Spatial Response Function Simulation: Physical Model

- The radiance for each AIRS footprint is a combination of 51 instantaneous fields of view (IFOV)
- IFOV spatial response function:
 - Pre-launch measurements
 - circle, ellipse, rectangle
- The spatial response function of the AIRS EFOV is the convolution product of the spatial response function of each IFOV and the integration time.
Other factors that we need to take into account are:
 - a: Time integration pattern
 - b: Scanning pattern / stepwise or continuous
 - c: Reflect mirror rotation / whether mirror is used
 - d: Satellite movement
 - e: Earth rotation
 - f: No spherical earth
- AIRS Sampling model: AIRS scan speed:8/3; 119 Sampling; 90Earthview
0.022 Integration Period; 51subsampling

AIRS Spatial Response Function Simulation Methodology

- Time Integration

- 0.022 second sampling period
 - Simulate sub sampling IFOV during the EFOV integration period
 - Project all sub sampling IFOV spatial response function on earth
 - Integrate IFOV spatial response function over EFOV sampling time

- Sub sampling

- 51 times
 - 51 sub scan angles
 - 51 sub satellite positions

- Satellite orbit calculation

- along track movement, 51 pointing vectors

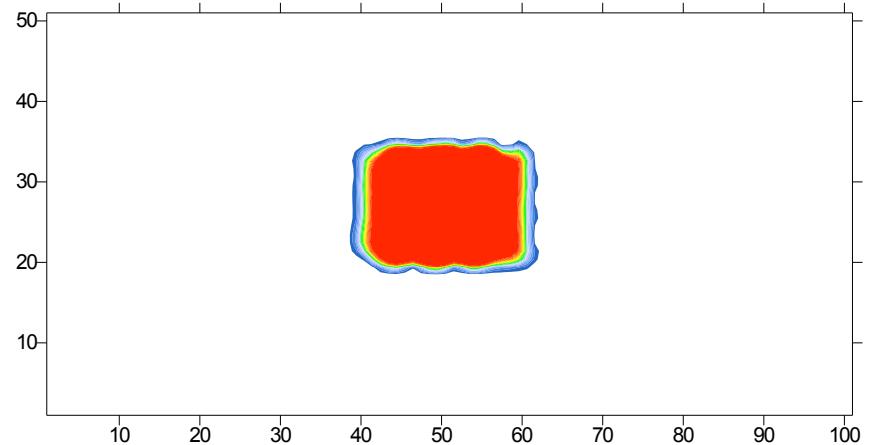
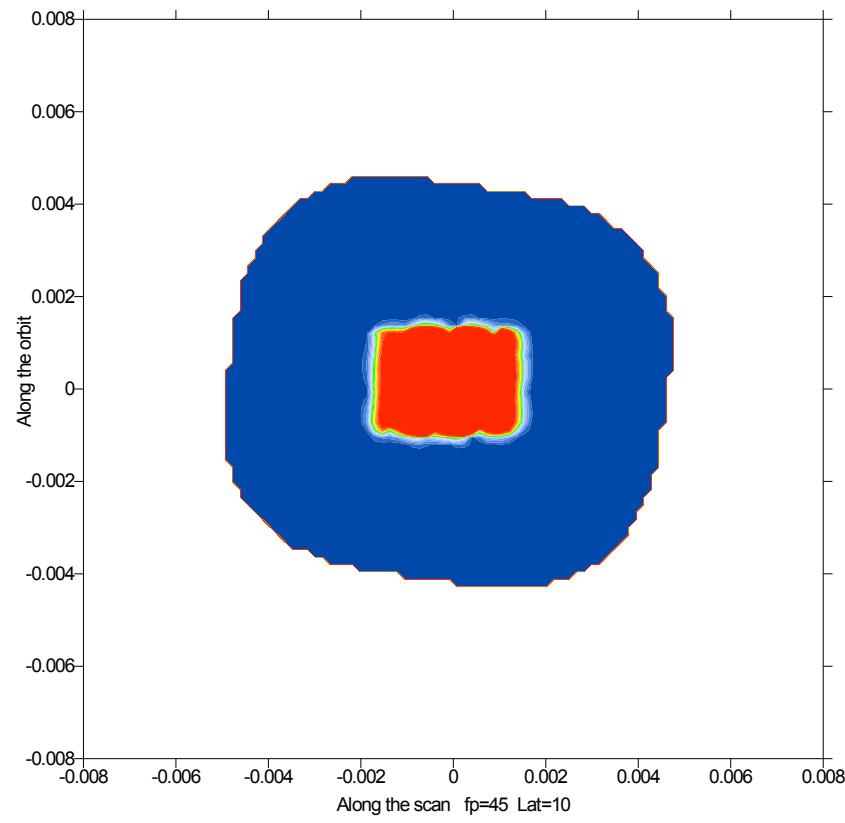
- Add Reflection mirror

- Use Earth elevation model (WSR84), non spherical

- AIRS EFOV spatial response function in earth surface coordinates:

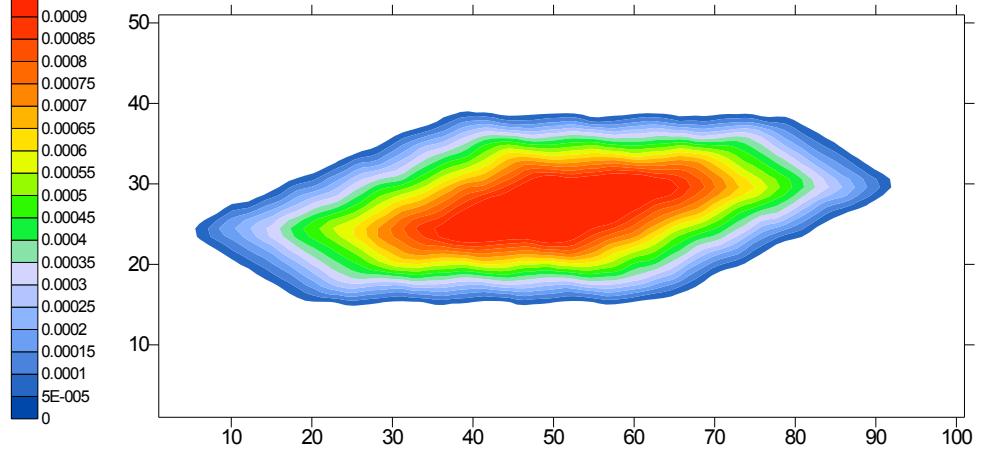
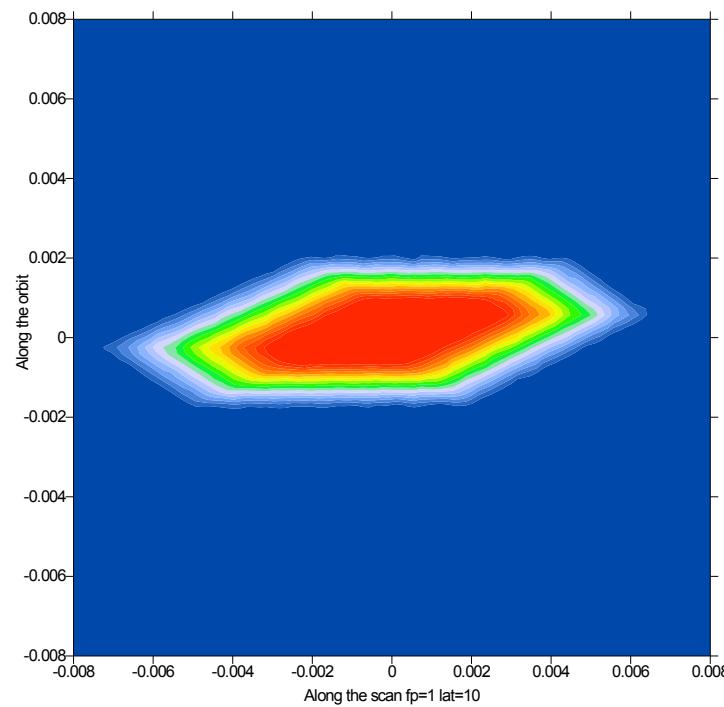
- 90 spatial response function for 90 scan angles.

AIRS EFOV Spatial Response Function Nadir View



AIRS EFOV Spatial Response Function

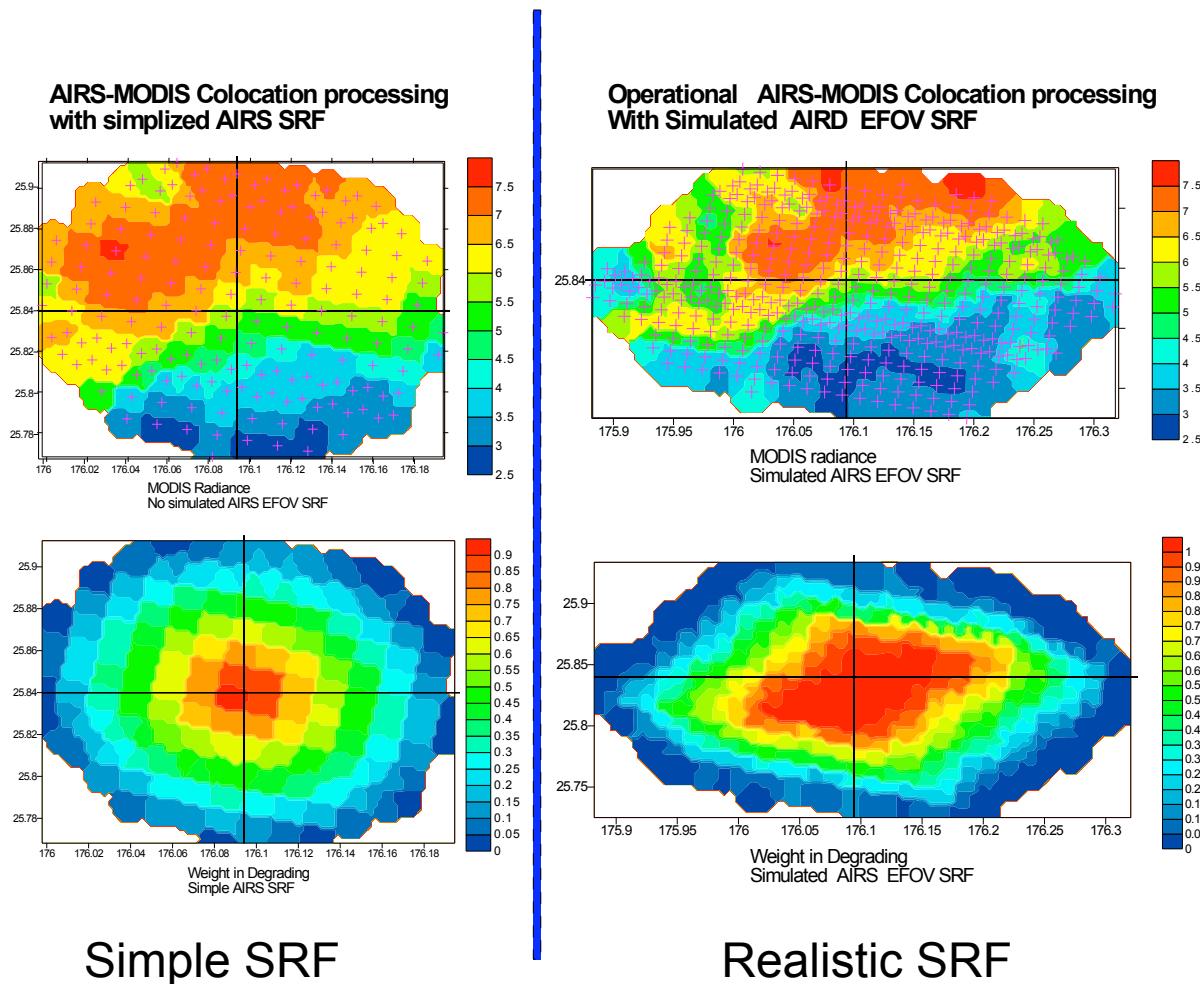
Opposite Edge of Scan



Algorithm Validation Results and Analysis

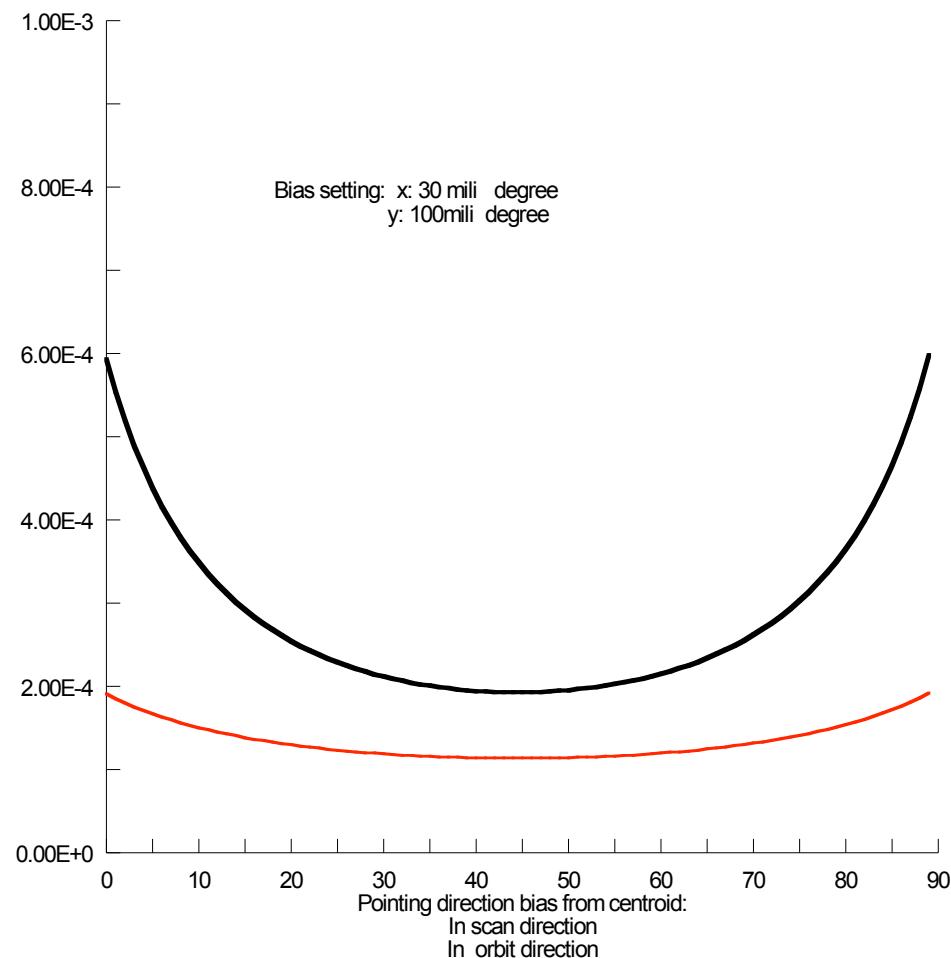
- Validation Method
- AIRS SRF application: AIRS pointing correction
- The problem in validation: MODIS Spectral Response Function
MODIS Spectral Response Function Retrieval
- Algorithm Validation with real Data:
 - Ocean Case Land Case
 - Polar Case Coastline Case Desert Coastline Case

AIRS EFOV Spatial Response Function Application



AIRS EFOV Spatial Response Function

Application: Pointing Bias Correction

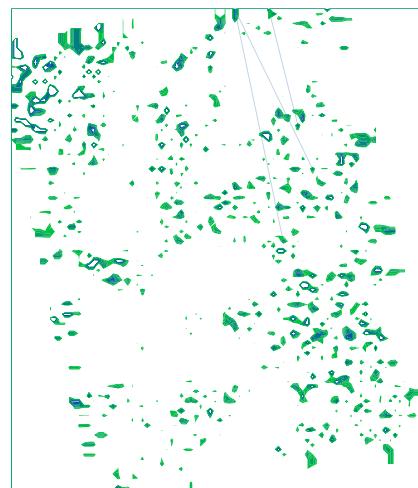


Low Latitude Region (Land) : 4/16/119 Ascending

Radiances

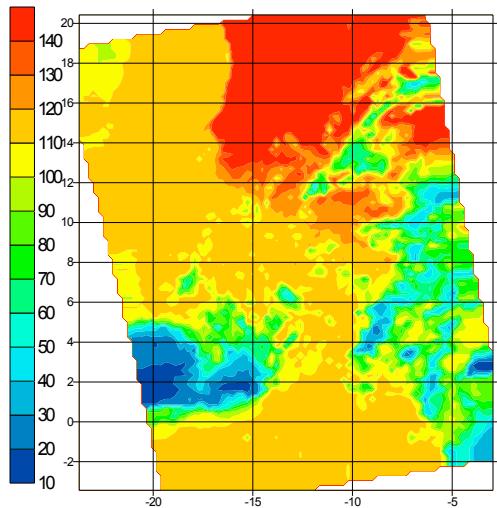
Simple SRF

Realistic SRF



Coastline: 04/17/143

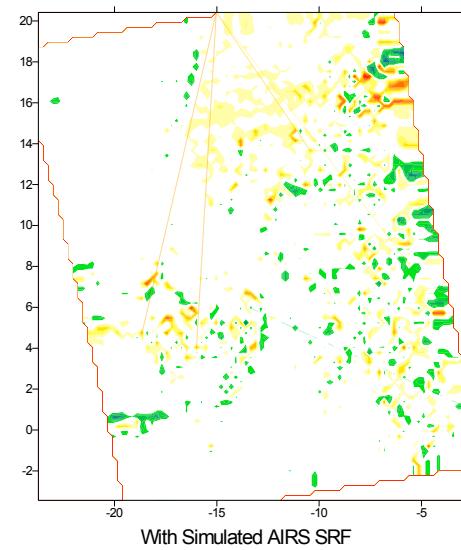
Radiance



Simple SRF



Realistic SRF



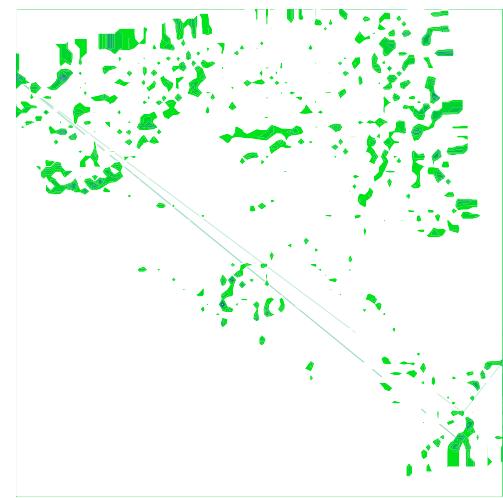
With Simulated AIRS SRF

Desert Coastline: 04/17/11

Radiance

Simple SRF

Realistic SRF



MODIS Response Function Retrieval

- **Part II MODIS IR channel Spectral Response Function**

MODIS Relative Spectral Response Function (RSRF) Problem

For the MODIS infrared channel 20-36, there is no way to monitor the instrument spectral sensitivity. Recent research about the MODIS observation data show that there may be different instrument spectral response function shifting in these 16 infrared channels.

For AIRS-MODIS co-location processing, an observation data based algorithm is developed to retrieve on-orbit ‘Broad band’ MODIS spectral response function with co-located AIRS high spectral resolution observation data.

The retrieved result provide the information of the ‘real’ MODIS RSRF on the observation system level. Those information can be used to improve the integration quality of different instrument and provide inter-instrument calibrilication ability.

Basic Methodology

- Basic equation: Individual MODIS IR channel

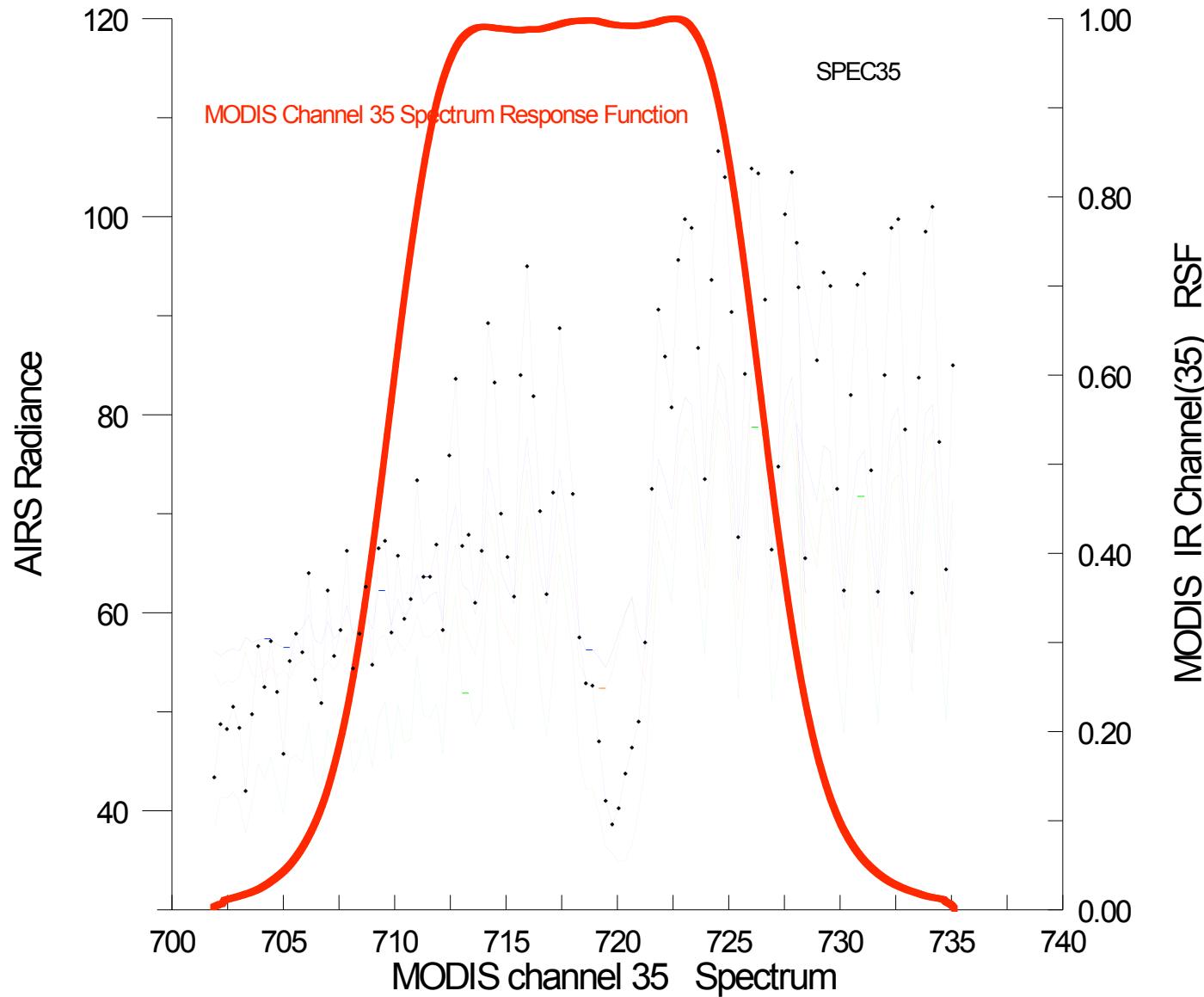
$$Rad_{MODIS} = \sum_i Rad_{AIRS} W_i$$

- $Rad_{(MODIS)}$: Low spectrum resolution MODIS observation
- $Rad_{(AIRS)i}$ High spectrum resolution AIRS observation
- W_i Weighting defined by spectral response function
- To resolve the W_i , A equation group is need:

$$A_{ij} X_j = M_i$$

- $A_{(I,j)}$: AIRS observation matrix
- $X_{(j)}$ Weighting vector
- $M_{(ij)}$ MODIS observation vector
- $I > J$ is required
- Key Assumption: All no-linear behavior is in-depend of wave length.

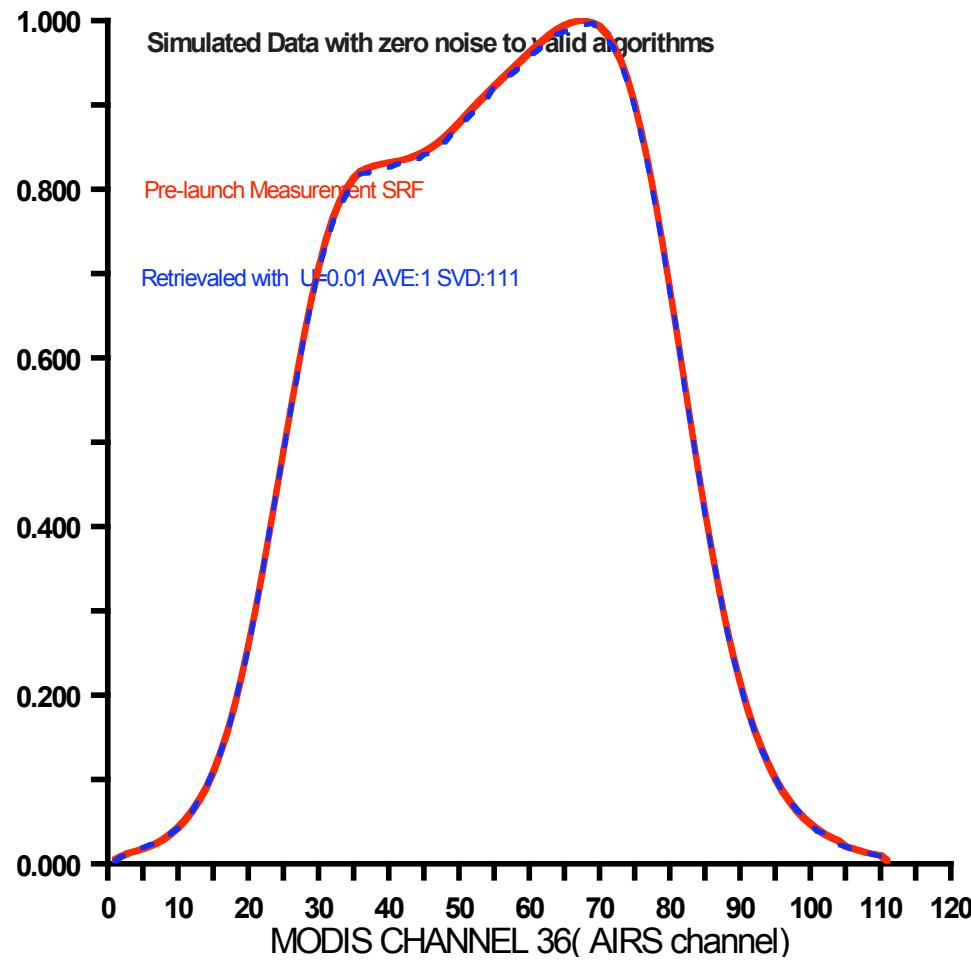
AIRS Inter-channel Sampling



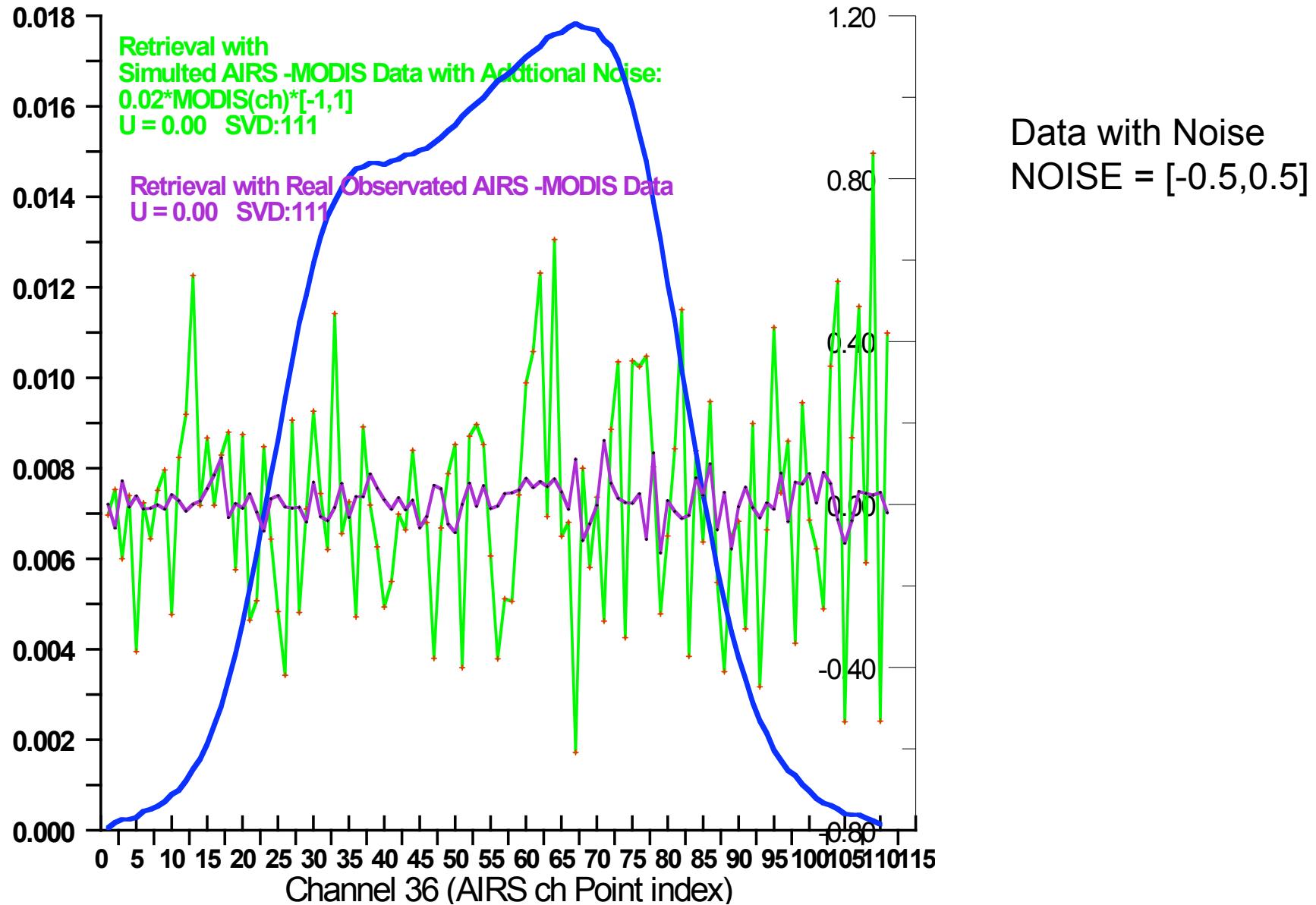
Deficient Matrix inverse Problem

- The X can be solved by multiplying both sides by the pseudo-inverse of A . But A is invariably rank deficient.
- Physically, X is continues with un-limited dimensionality. The A and M are tend to be low dimensionality.
- With rank deficient A , M , Retrieval of X based on matrix inversion are very sensitive to noise

Retrieval with Simulated Data



Retrieval with Simulated Data



Improved Methodology: Retrieval with deficient Matrix

Data set Optimization:

Co-located MODIS–AIRS Date/ Uniform scene.

Apply the AIRS spatial response function

Differential equation: Remove system bias.

Average Equation to reduce the Observation white noise

Deficient Matrix Equation Optimization:

Regulate Matrix A with Truncated Singular decomposition:

Noise Reduction: Truncate small singular values

Constraint Retrieval algorithm : Constraint

Retrieval/Selection.

Retrieval average

Simultaneous optimization Retrieval with Physical constraining

Constraints:

1. RSF positivity

$$X_j \geq 0$$

2. RSF smoothness

$$|X_j - X_{j+1}| \leq T$$

3. RSF Bounded prediction

$$|M_i - \sum_{j=1}^l A_{ij} X_j| \leq \varepsilon$$

4. Modality

5. RSF rank constraint

6. RSF border limitation

Smoothness Weighting factor:

$$f = \|M_i - \sum_{j=1}^l A_{ij} X_j\|^2 + \lambda X^T D X \Rightarrow \min$$

$$\frac{\partial f}{\partial x} = 0$$

$$D = \begin{pmatrix} 1 & 0 & 0 & 0 \\ -1 & 2 & -1 & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Retrieval Algorithms Numerical Test

Purpose: Validate the Retrieval algorithms

Validation Method:

Retrieval with simulated AIRS /MODIS Data set to test whether This algorithms can obtain useful retrieval result when observation noise exist.

Data set:

AIRS Data: AIRS Observation data

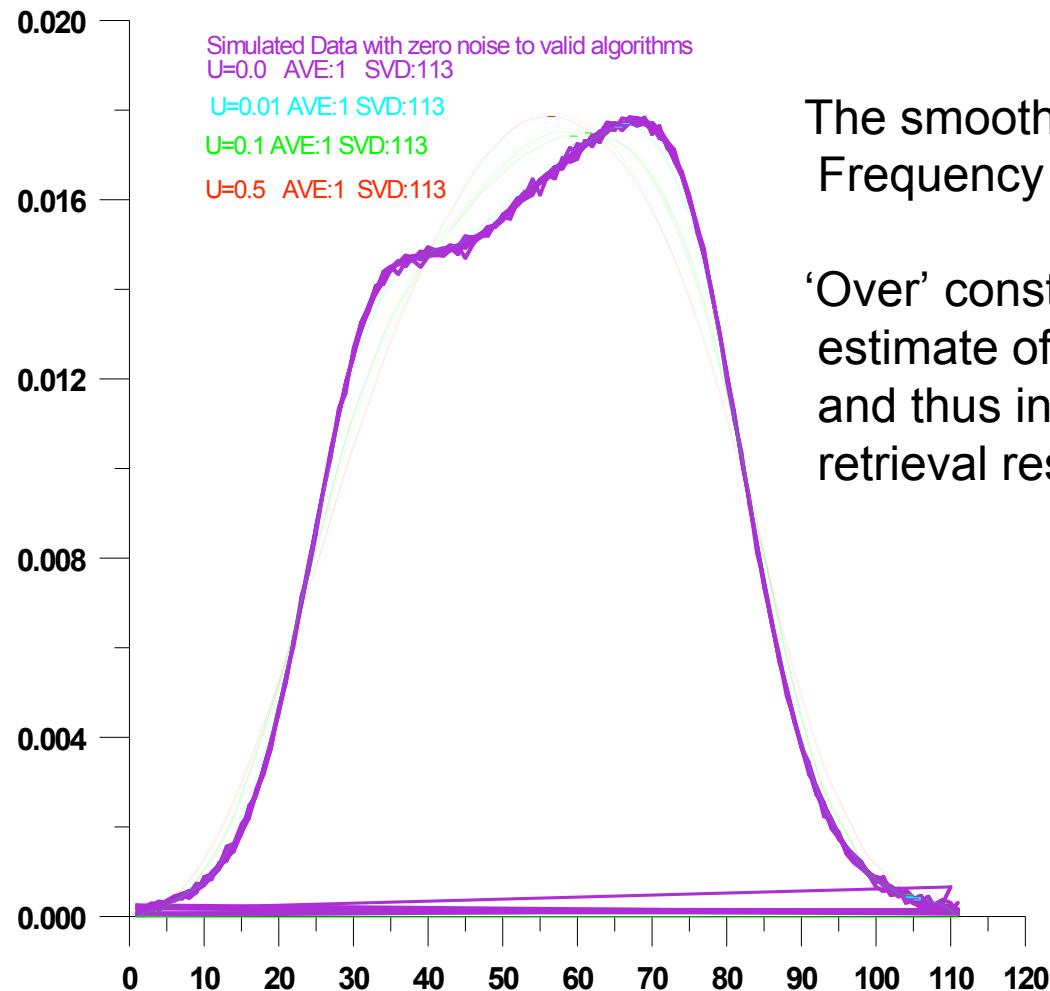
MODIS Data: AIRS Convolution product With pre-launch measurement MODIS RSRF

Noise Model: Free noise/System Bias/White Noise / Observation related noise

F noise Model

$$\text{NOISE} = -1.242 + [-1, 1] + 0.01 * \text{Rad(MODIS)} + 0.01 * \text{Rad(MODIS)} * [-1, 1]$$

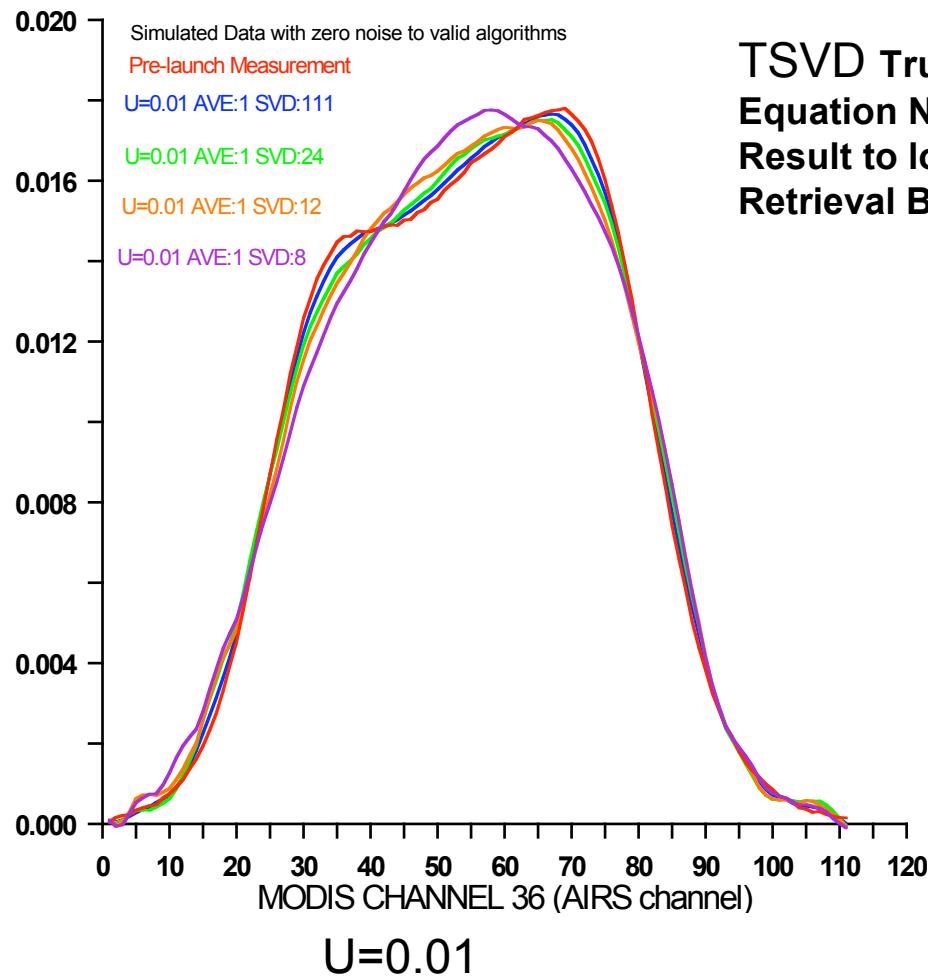
Constrain retrieval with Free noise Data



The smooth constrain will limit the high Frequency Component in retrieval result.

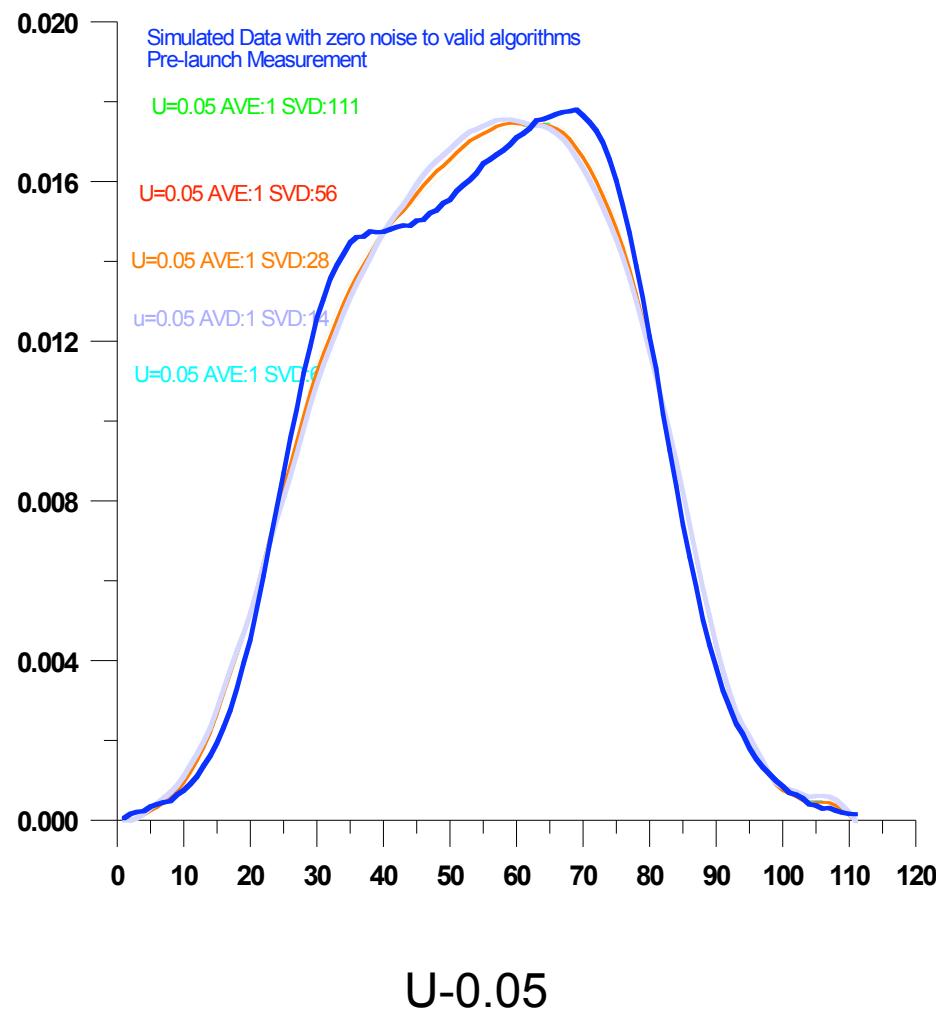
'Over' constrain will lead to the 'under estimate of the high frequency component and thus introduce retrieval Bias between retrieval result and the 'Truth'.

TSVD & Retrieval Bias

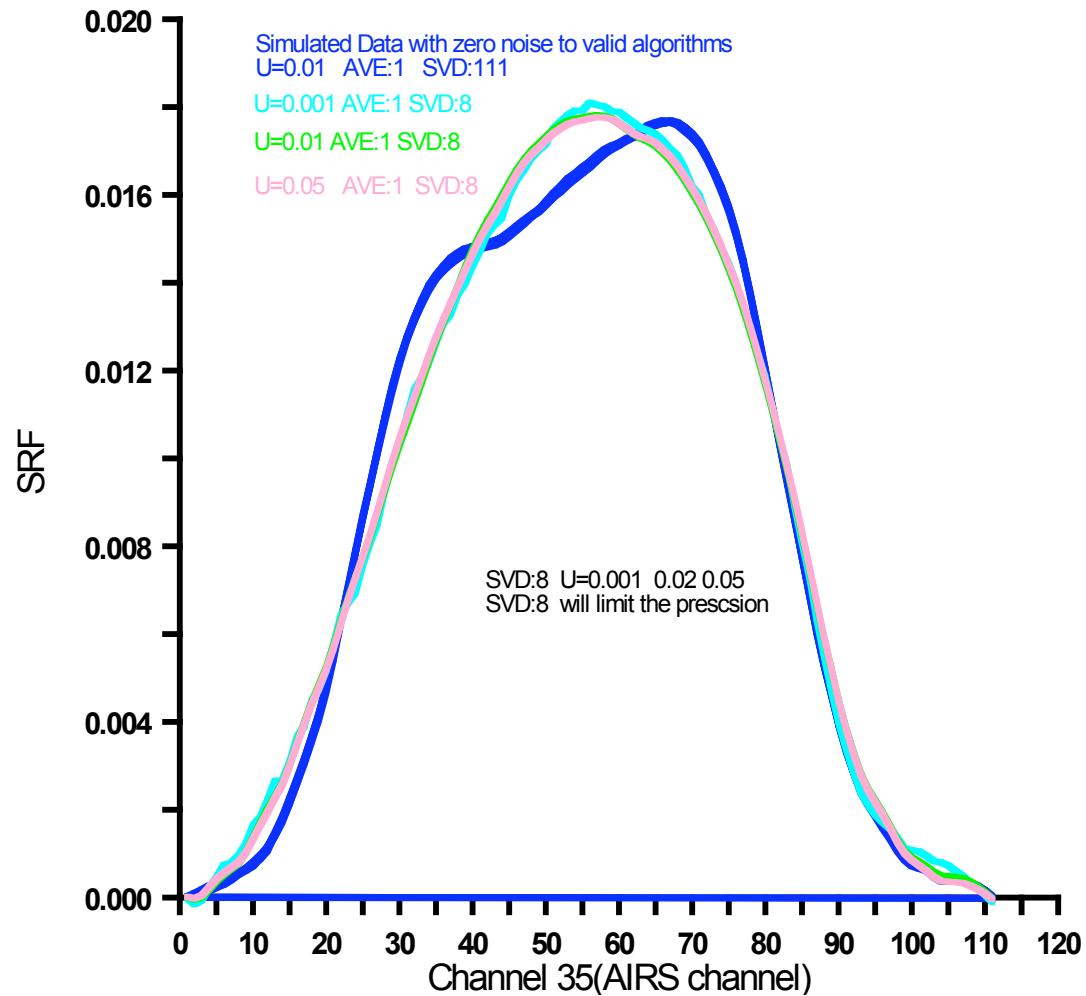


TSVD Truncated small Singular factor to reduce the Equation Noise sensitivity, It will also lead to the retrieval Result to lost the high frequency component and introduce Retrieval Bias.

TSVD & Retrieval Bias

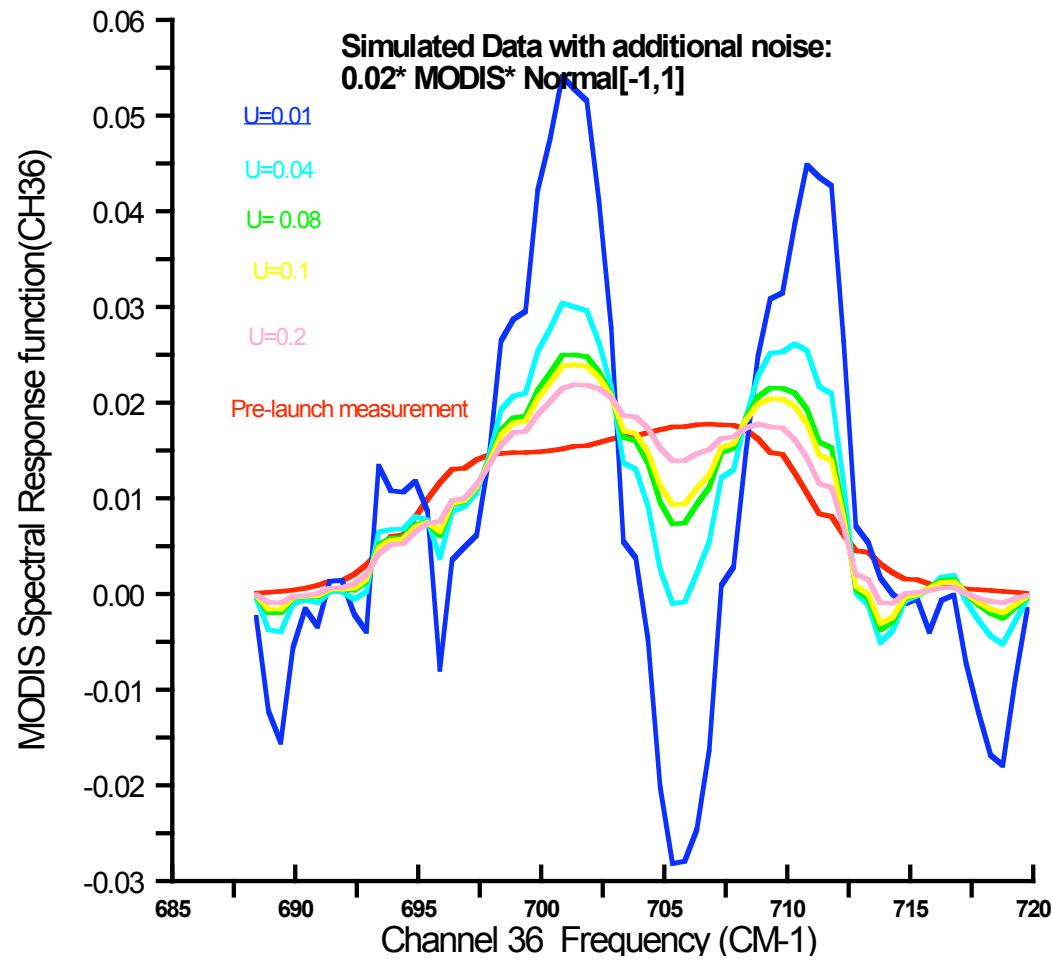


TSVD & Constraint&Retrieval Bias

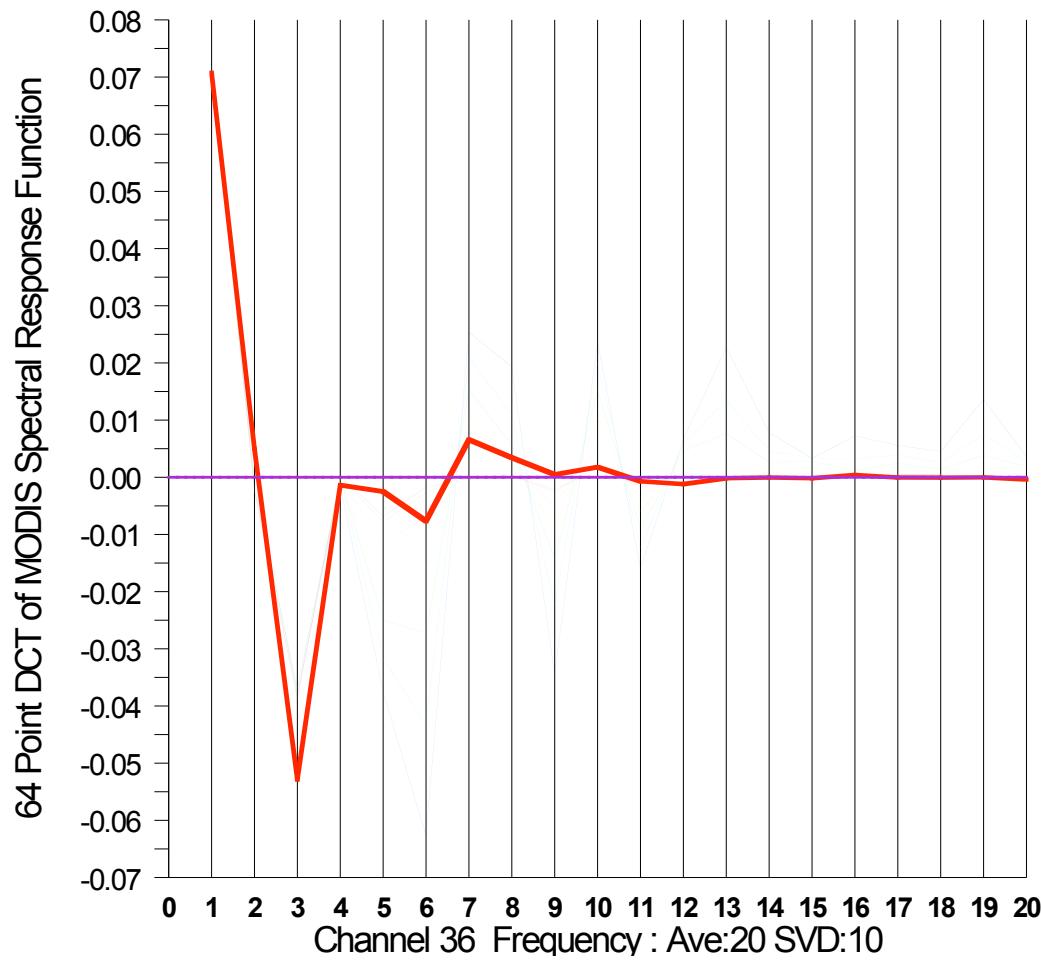


Algorithms Validation

Simulated MODIS observation with noise

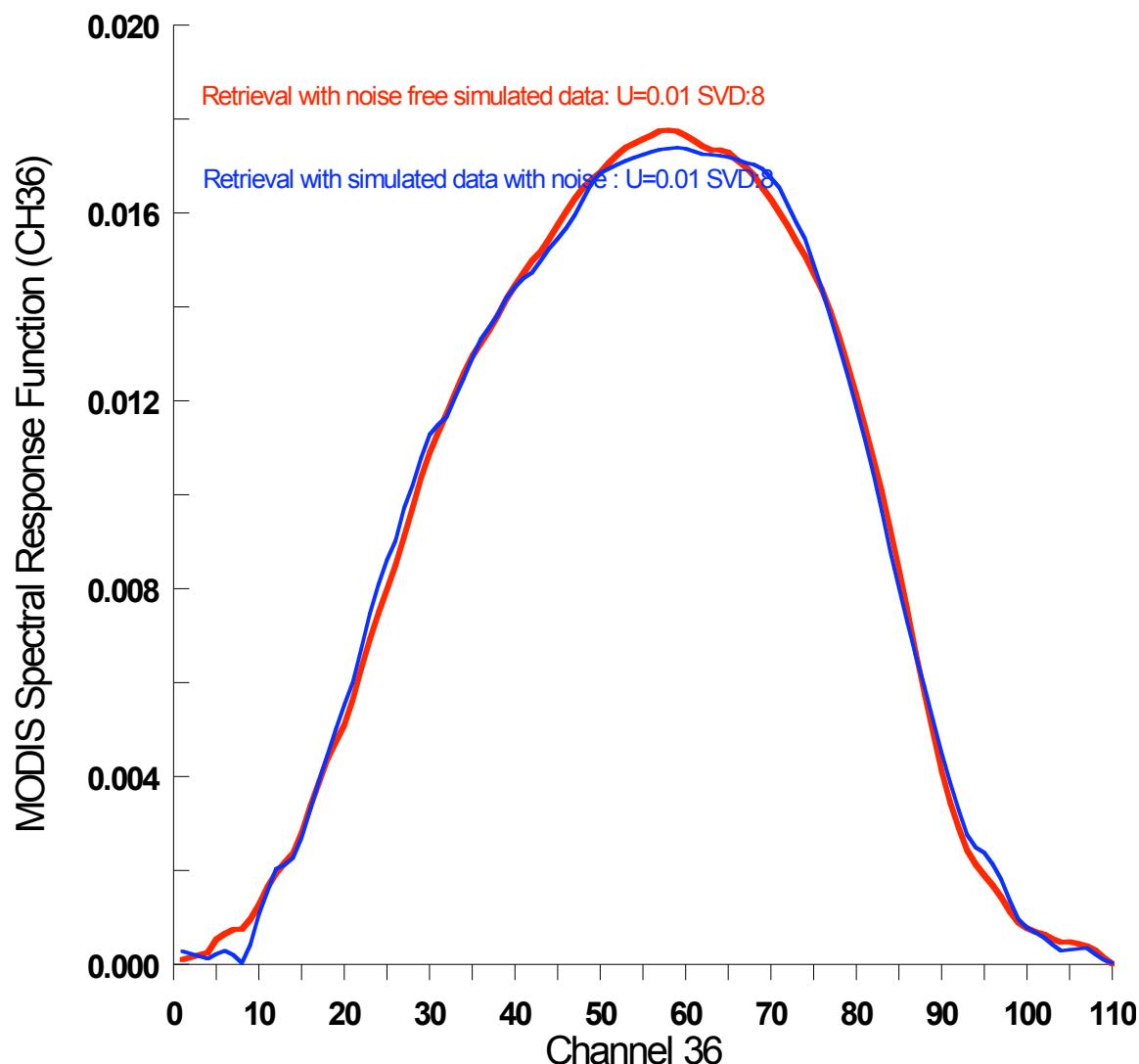


RSF smoothness constraint

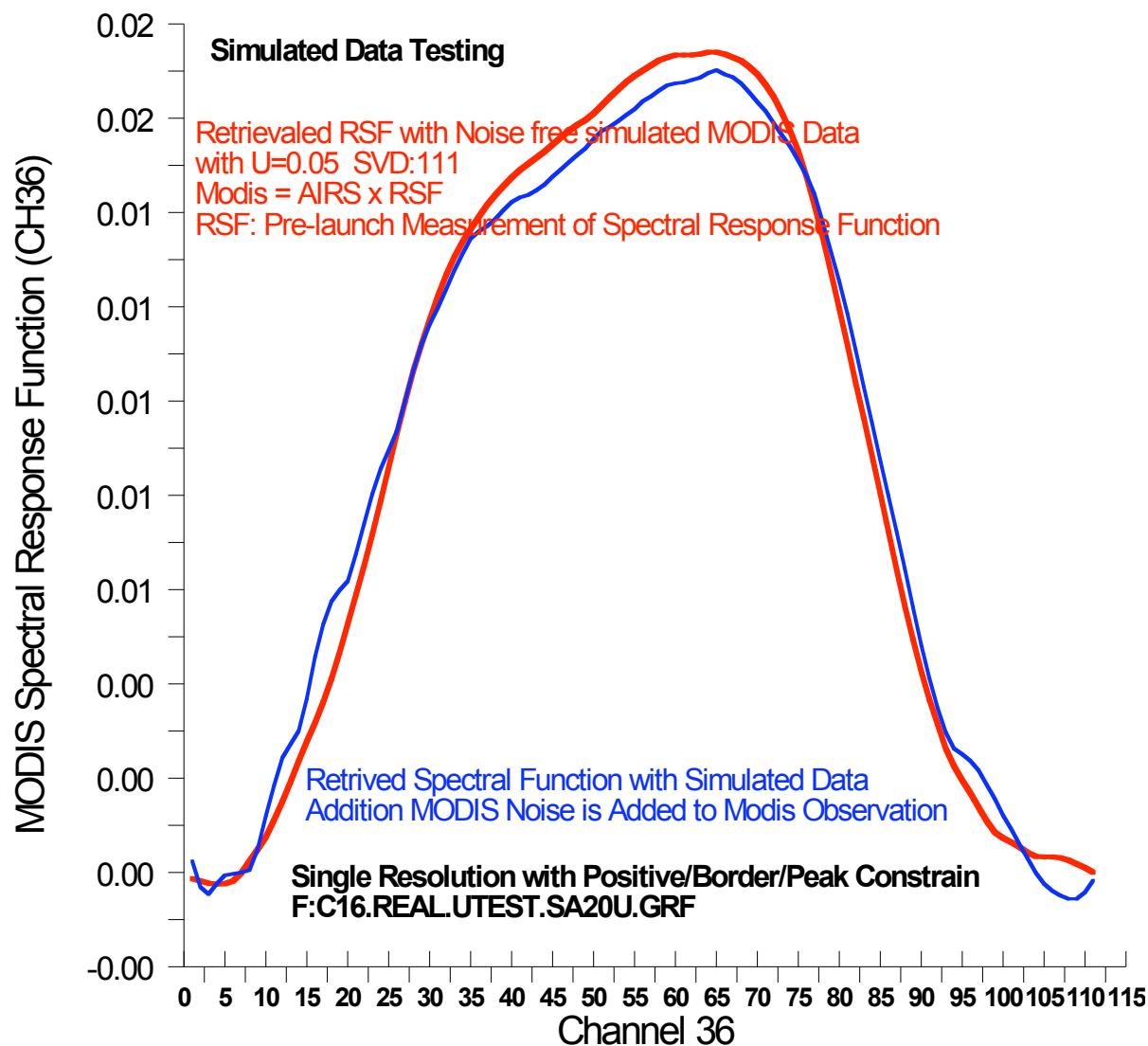


PS:
Different between
simultaneous optimization
and low pass fileter

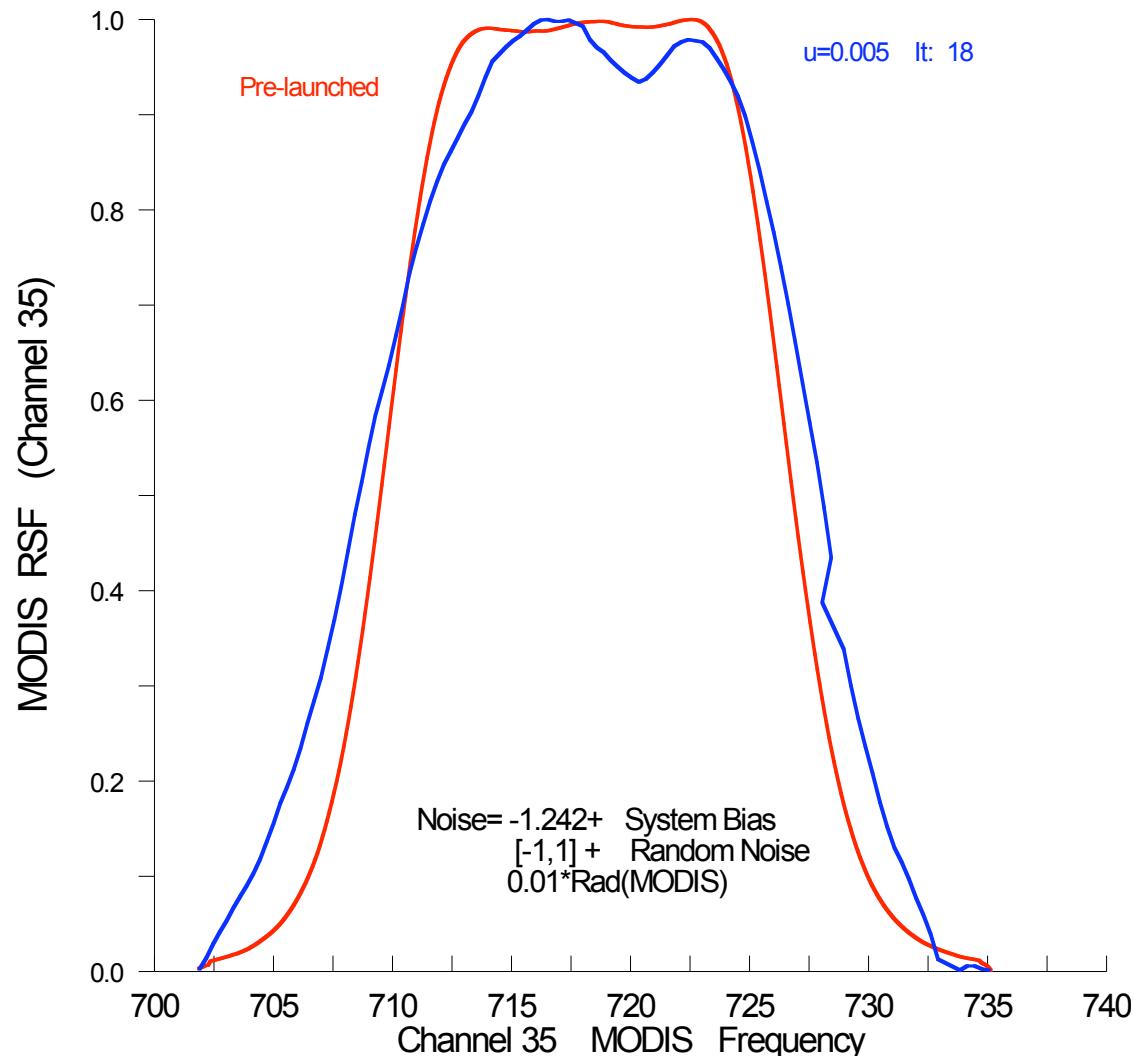
Algorithms Validation with Simulated Data



Algorithms Validation with Simulated Data

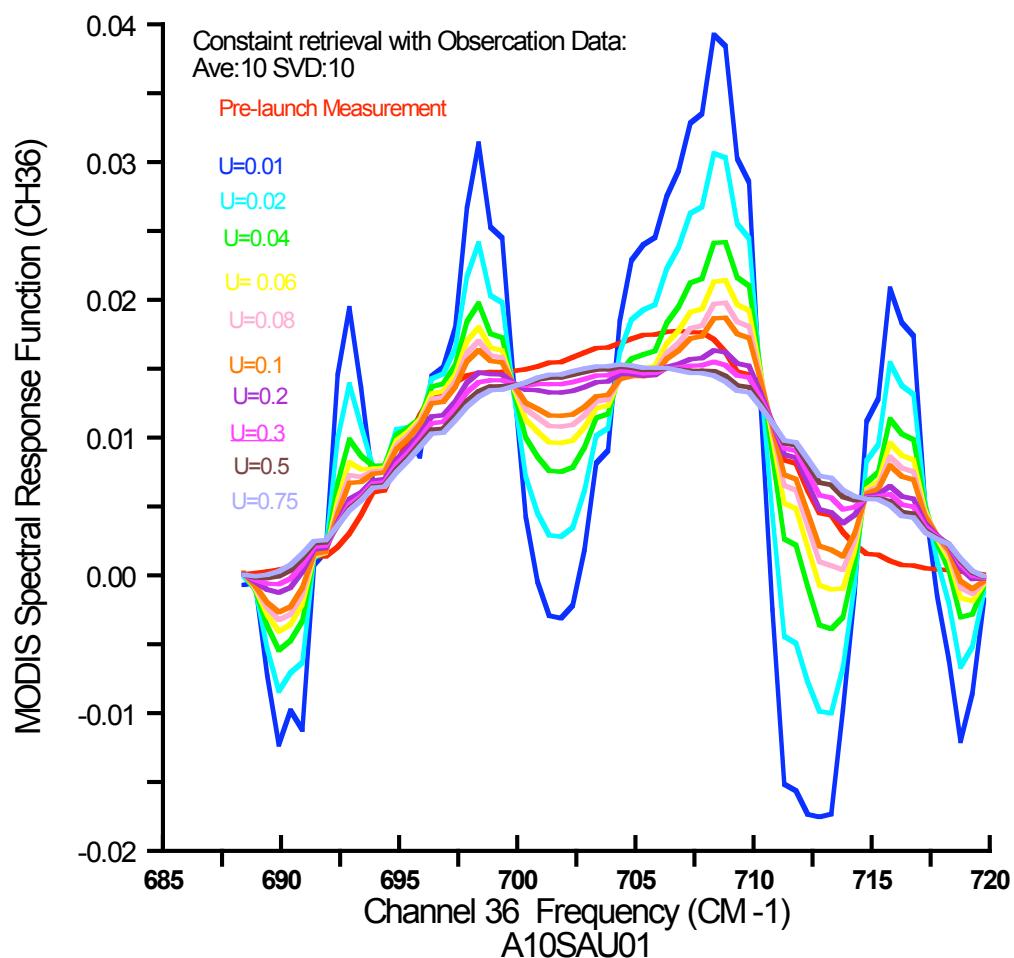


Algorithms Validation with Simulated Data

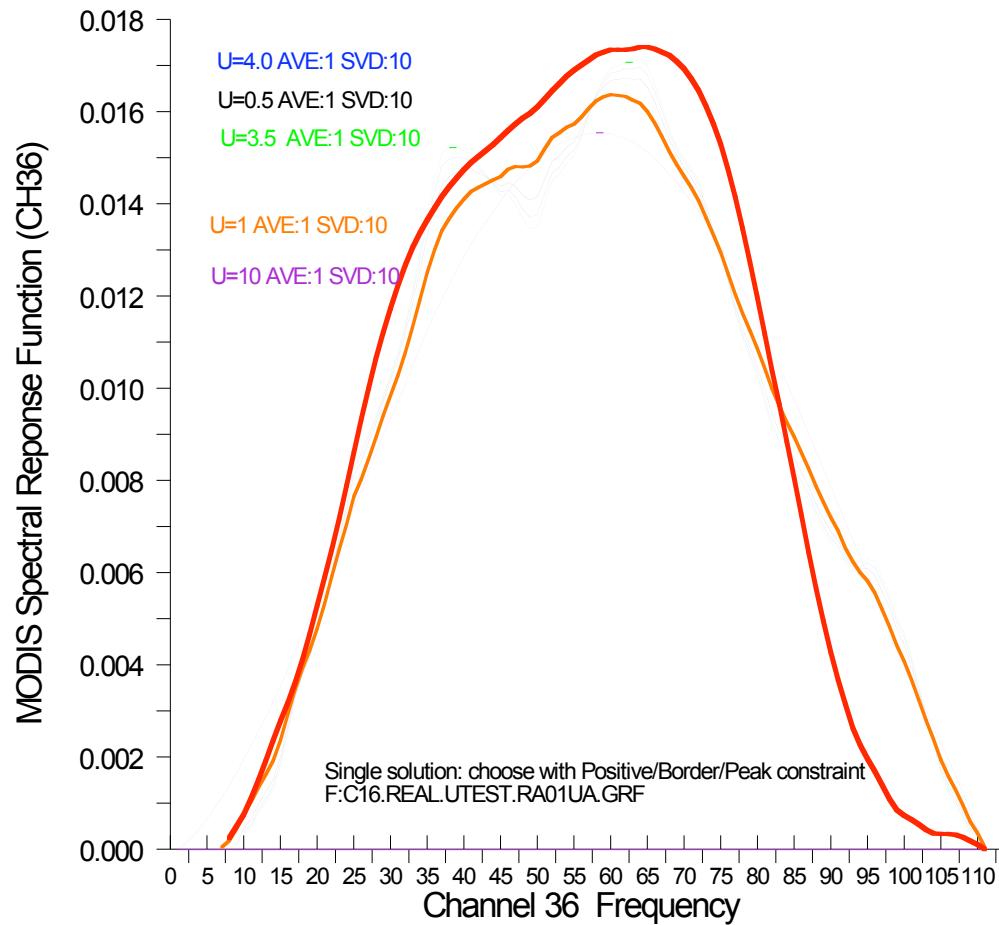


Retrieval Result Analysis

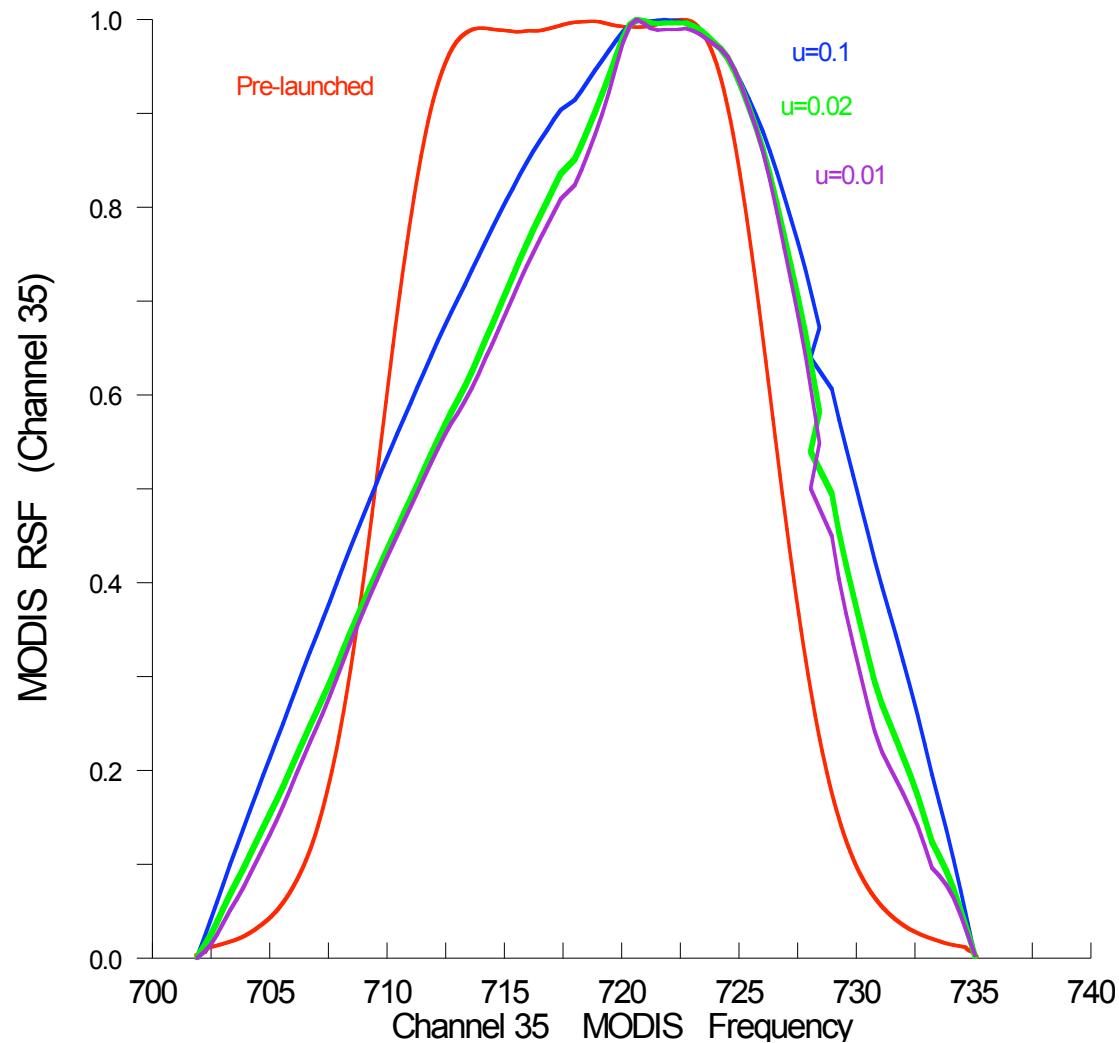
Constraint Retrieval with Observation Data



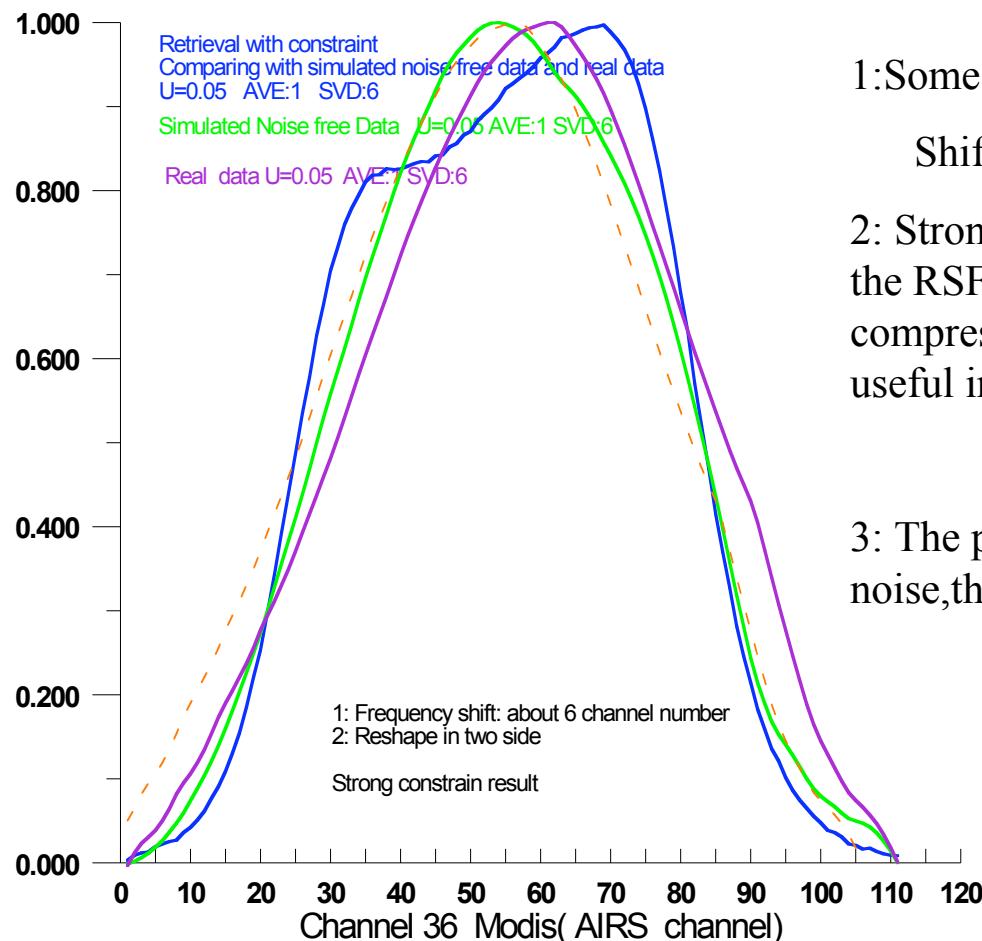
MODIS channel 35 RSRF Retrieval



MODIS channel 35 RSRF Retrieval



Precise result and constrain degree

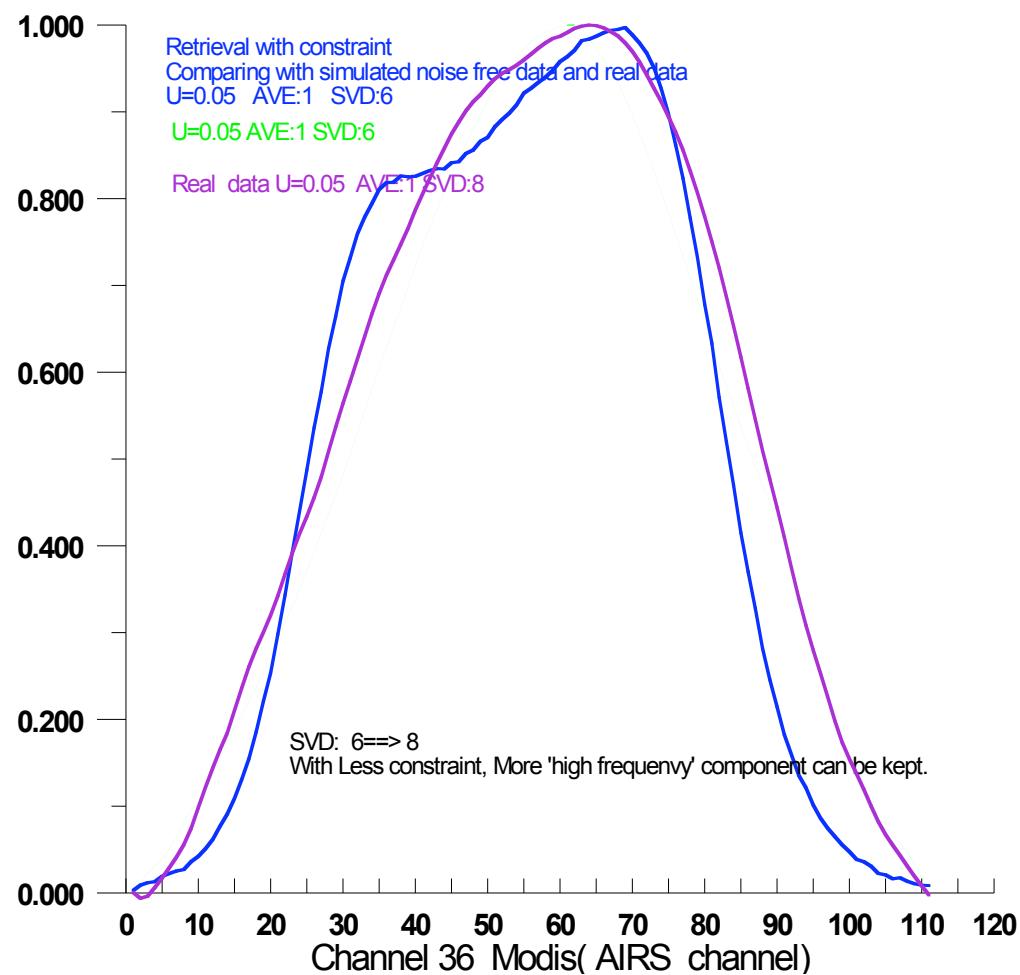


1: Some information we can get with this retrieval
Shifting and reshape.

2: Strong constraint will lead to detail structure of the RSF be to smoothed. When the noise is compressed, the high frequency component useful information is also depressed.

3: The precision and the compression of the noise, that is a comprise.

Biased Constraint retrieval



Noise sensitivity & Constraint bias

The bias introduced by constraint condition depend on:

The SRF pattern.

If In SRF, the high frequency component is small, the bias introduced by constrain is small. The retrieval can be used as SRF.

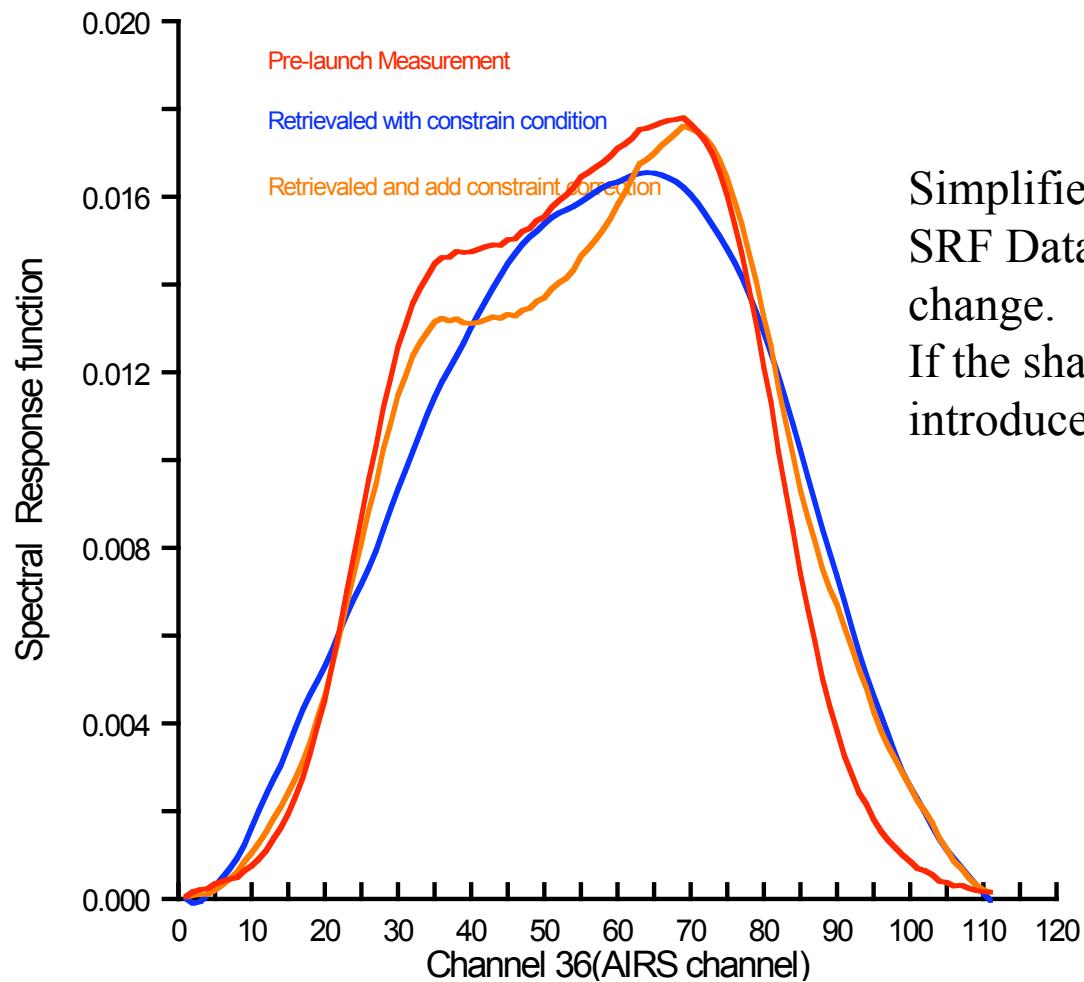
Constraint strength.

Weak constraint mean strong noise sensitivity.

Solution:

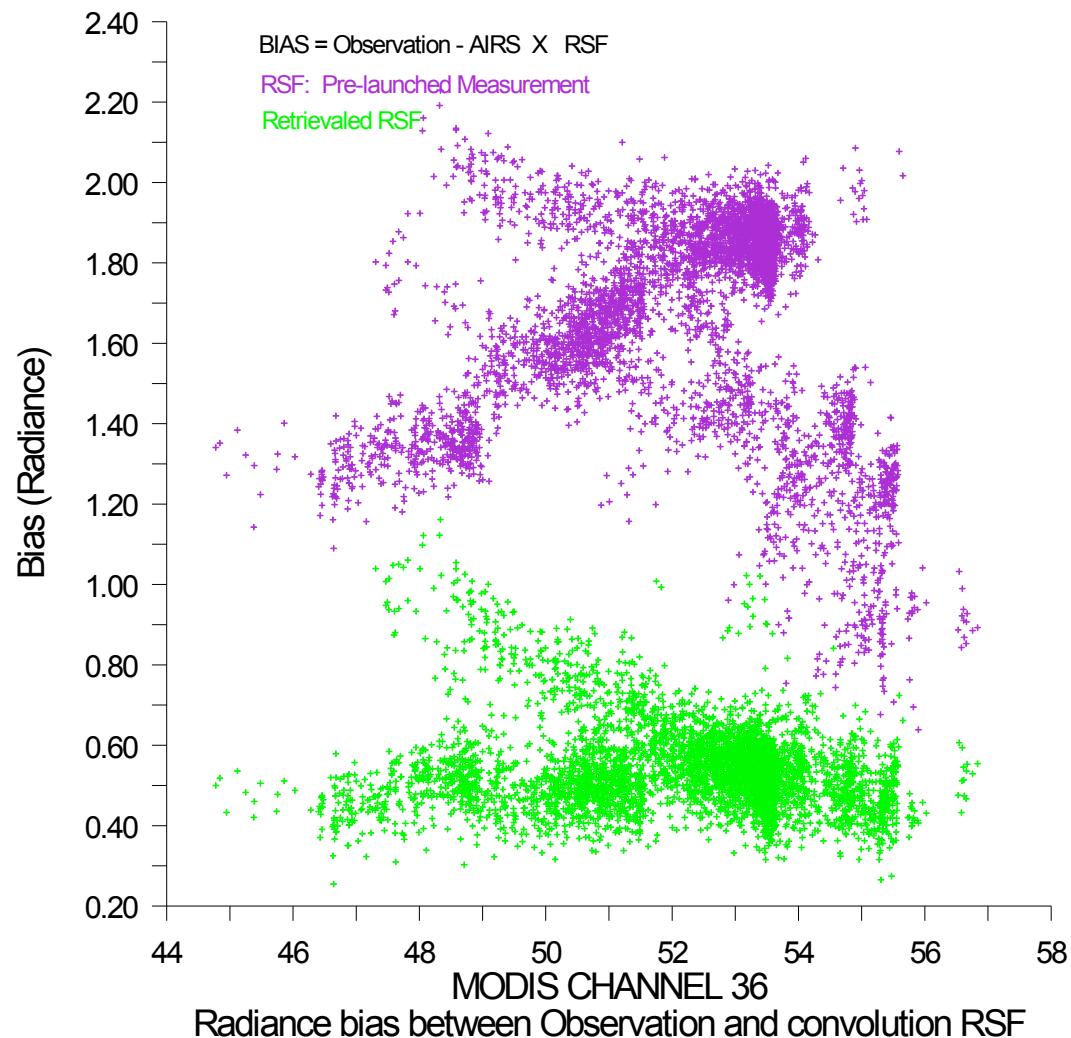
- 1: Limit the noise in data will reduce the requirement of the constraint.
- 2: High frequency component compensation.

Constraining bias correction



Simplified correction model basing on the SRF Data and assumption that slight shape change.
If the shape change is great, the correct will introduced bias

Evaluation for channel 36



Summary

- AIRS spatial response function can be used to improve the collocation accuracy.
- AIRS pointing bias and MODIS spectral change make the collocation problem more complex.
- Constraint retrieval algorithms can be applied to obtain MODIS RSF information with AIRS high spectral resolution information. This application reveal that the inter-instrument Calibralition is possible and useful.
- The multi-sensor remote sensing data integration and inter-calibration will beneficial to retrieval and calibration both.